Sci & Educ (2009) 18:1105–1113
DOI 10.1007/s11191-008-9163-5

Can Science Education Research Give an Answer to Questions posed by History of Science and Technology? The Case of Steam Engine's Measurement

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Published online: 31 July 2008

Abstract According to the principle of virtual velocities, if on a simple machine in equilibrium we suppose a slight virtual movement, then the ratio of weights or forces equals the inverse ratio of velocities or displacements. The product of the weight raised or force applied multiplied by the height or displacement plays a central role there. British engineers used the same product in the eighteenth century in order to measure steam engines' effectiveness. The question is whether this measure was obviously empirical or had its origin in theory of mechanics and particularly in the principle of virtual velocities. According to science education research, this measure is not likely to have arisen intuitively and most probably could not have been formulated without any acquaintance with theory of mechanics.

1 Introduction

Research in science education often surveys history of science and technology literature in order to collect ideas, stories and experiments, and use them to achieve research or educational aims (Matthews 1994; Seroglou and Koumaras 2001; Koliopoulos et al. 2007). What I will try to do here is exactly the opposite. I will attempt to use science education research in order to answer a question posed by historians of science and technology. The subject to be examined refers to the product of the weight raised by a steam engine per minute by the height of its elevation, which was used by the British engineers of the eighteenth century as a measure of steam engines' effectiveness. The question is whether this procedure was a 'fairly obvious empirical measure of the effectiveness' of the engine (Hills and Pacey 1972, p. 29) or 'necessarily implies understanding and acceptance of Galileo's principle', that is the principle of virtual velocities (Cardwell 1967, p. 215).

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2 The Principle of Virtual Velocities

In antiquity, two traditions were developed for the study of ‘mechanics’ (i.e., statics[1]). The first one, presented by Archimedes and based on the law of the lever (Archimedes 1972), will not bother us here. The second, firstly presented in the Aristotelian[2] *Mechanical Problems*, was based on what in the eighteenth century will be called ‘principle of virtual velocities’. According to this principle, in order to state the condition of equilibrium of a system of bodies, we assume a small hypothetical or virtual movement for the system and equate the ratio of weights or forces to the inverse ratio of movements or velocities.[3]

> Now the ratio of the weight moved to the weight moving it is the inverse ratio of the distances from the center. Now the greater the distance from the center describes the greater circle, so that by the use of the same force, when the motive force is farther from the lever [fulcrum], it cause a greater movement. (Aristotle 1980, *Mechanical Problems* 3, p. 850b)

This tradition will be continued in a series of medieval texts on the ‘science of weights’, will come down to the hands of Cardano and Tartaglia in the Renaissance, and will be passed over to Galileo and Descartes in seventeenth century (Duhem 1905, pp. 75–165; Hiebert 1962, pp. 28–45). Galileo described the Aristotelian principle, in brief, in his ‘*Dialogue concerning the two chief world systems*’, edited in 1632, as follows:

> SAGREDO… In both instruments, weight and motion are involved; in the balance, the movements are equal and therefore one weight must exceed the other in heaviness in order to move. In the steelyard, the lesser weight moves the greater only when the latter moves very little, being weighted at the lesser distance, and the former moves quite a way, hanging at the greater distance. One must say, then, that the smaller weight overcomes the resistance of the greater by moving much when the other moves little.
>
> SALVIATI. Which is to say that the speed of the less heavy body offsets the heaviness of the weightier and slower body.
>
> SAGREDO. But do you believe that this speed exactly compensates that heaviness? That is, that the moment[4] and the power of a moving body of say four pounds weight are as much as those of a body weighting one hundred, whenever the former has one hundred units of speed and the latter only four units?
>
> SALVIATI. Certainly, as I can show you by many experiments. (Galilei 1632, p. 249)

Galileo presented a more detailed description of the Aristotelian principle in his lectures on mechanics (statics) at the University of Padua, edited in 1634 by Marin Mersenne, under the title ‘*The Mechanics of Galileo*’ (*Les mécaniques des Galilée*). There, Galileo not only

[1] Until the eighteenth century, the term ‘mechanics’ refered to the study of simple machines, that is statics.

[2] Most probably, the book was written by a student of Aristotle and not Aristotle himself (Duhem 1905).

[3] Since time is the same, the ratio of movements is equal to the ratio of velocities.

[4] ‘Moment’ (momento) for Galileo determines a body’s power in mechanical situations and depends on the body’s weight, the effective distance at which it acts and its velocity. Hence, the term ‘moment’ sometimes means something like ‘static moment’ and sometimes something like ‘momentum’ (see Drake’s introduction in Galileo 1960).

did make systematic use of the principle, but also developed convincing arguments in its favor.

> …for even though the force be very small, by dividing the weight into many particles of which each shall not remain superior to the force, and transferring them one at a time, the whole weight will finally be conducted to the appointed place; nor may it reasonably be said at the end of this operation that this great weight has been moved and translated by a force which has many times repeated that motion and space which will have been traversed only once by the whole weight. From which it appears that the speed of the force has been greater than the resistance of the weight by as many times as this weight is greater than the force…
>
> But since it may sometimes happen that, having but a small force, we need to move a great weight all at once without dividing it into pieces, on such an occasion it will be necessary to have recourse to the machine, by means of which the given weight will be transferred through the assigned space by the given force; yet this does not remove the necessity for that same force to travel and measure that same (or an equal) space as many times as it is exceeded by the said weight. (Galileo 1960, pp. 148–149)

René Descartes based his statics on the same principle. In 1637, he wrote the small treatise '*An explication of machines with which one can raise a very big weight with a small force*' (*Explication des engines par l' ayde desquels on peut, avec un petit force, lever un fardeau fort pesant*). There, he deduced all theory about simple machines from the single principle that the 'force' needed to raise a weight depends both on the weight and the height of elevation.[5] Descartes tried to justify this principle with the metaphysical statement that any result is bound to be proportional to its cause.

> The invention of all these machines is based on a single principle: the force which can raise a hundred-pound [libre[6]] weight, for example, to the height of two feet, can also raise a two-hundred-pound weight to the height of one foot, or a four-hundred-pound weight to the height of half a foot etc., provided that the force remains the same.
>
> And this principle must be accepted, if one believes that the effect should always be proportional to the action needed to produce it. (Descartes 1996, tom. I, p. 437)

The Aristotelian principle was stated with mathematical rigor and took the name "principle of virtual velocities" by Johann Bernoulli and Pierre Varignon in Varignon's book "*New Mechanics or Statics*" (*Nouvelle mécanique ou statique*), edited in 1725 (Varignon 1725 in Maggie 1969, pp. 49–50). In the nineteenth century the principle was renamed 'principle of virtual work'.

3 Measuring Steam Engine's Effectiveness

Steam engines appeared in Britain in the eighteenth century, and by the end of the century they had dominated the industrial landscape. The first, more primitive, types of steam engines were built at the beginning of the eighteenth century by Thomas Savery and

[5] In a letter to Mersenne, he explained that this 'force' is different from the force necessary to support a weight since it has two dimensions: the force supporting the weight and the height of elevation.

[6] In fact, the French 'livre' was slightly heavier than the English 'pound'. Approximately 1 livre = 0.490 kg whereas 1 pound = 0.454 kg (Roche 1998).

Table 1

A *Physico-Mechanical* Calculation of the Power of an *Engine*.

Diamerer of the Pump Inches.	Draws at a 6 Foot stroke.	at 16 St. in a Min. draws per Hour.	The Depth to be Drawn in Yards.												
Inch	Ale Gall.	Hogsh. Gall.	15	20	25	30	35	40	45	50	60	70	80	90	100
			The Diameter of the Cylinder. Inches												
4	3. 20	48. 51					9	10	11	11½	12	13½	14	15	16
4½	4. 04	60. 60				10	11	11¼	12	13	14	15	16	17	18¼
5	5. 02	66. 61			10	11	11¼	13	13¾	14	15½	16¼	18½	19½	20¾
5½	6. 26	94. 30		10	11	12	13	14	15	15¼	17	19	20	21	22¼
6	7. 22	110. 1	9½	11	12	13	14	15½	16	17	19	20½	22	23	24½
6½	8. 46	128. 54	10	12	13	14	15½	16¼	18	19	20	22	23	24½	26½
7	9. 82	149. 40	10¼	13	14	15½	16¼	18¼	19	20½	22	24	25½	27	28½
7½	11. 32	172. 30	11	13¼	15	16½	18	19	20	21¼	23½	25	27	28½	30¼
7¾	12. 02	182. 12	12	14	15½	17½	18¼	19¾	21	22	24¼	26	28	29	31½
8	12. 82	195. 22	12½	14½	16½	18½	19	20½	21½	23	25	27	29	30½	32½
8½	14. 52	221. 15	13½	15¼	17¼	19	20¼	21¼	23	24	26¼	28½	31	32½	35¼
9	16. 24	247. 7	14	16½	18	20	21½	23	24¼	25	28	30½	33	35	36½
10	20. 04	304. 48	15½	18	20	22	23¼	25½	27	28¾	31¼	33¾	36	38½	40

Thomas Newcomen, whereas in 1776 James Watt launched a more sophisticated type of steam engine, with much greater efficiency.

Originally, steam engines were built to move the pumps for the mines' drainage, and engineers saw them as powerful pumps. Their effectiveness (engineers used the term 'duty') was measured by the quantity of water (usually in pounds) that an engine could raise one foot high in 1 min or with the consumption of one bushel[7] of coal. This measure was directly connected with another measure of the steam engine's 'duty': the 'horse'[8] or 'horse power'. A 'horse', according to the measure given by Watt, which had prevailed in Britain by the end of the eighteenth century, was equivalent to 33,000 lb raised 1 ft in 1 min (Cardwell 1967, p. 215; Hills and Pacey 1972, p. 30).

In 1717, for example, Henry Beighton, an engineer, estimated the powers of a Newcomen steam engine, and this data is presented in table 1 ('*Ladie's Diary*' magazine, 1721, cited in Dickinson 1938, pp. 43–44). On the third column, there appear the quantities of water (in hogheads[9] and gallons) raised per hour, from different depths (in yards) and for different diameters of the engine's cylinder (in inches).

In 1769, another engineer, John Smeaton, collected data for 15 steam engines in the North of England, and estimated that, on average, they were raising 5,590,000 lb of water 1 ft high with the consumption of 1 bushel of coal. In 1772, Smeaton improved Newcomen's steam engine, doubling its 'duty'. The first of these engines, built in Long Benton colliery, Northumberland, achieved a 'duty' of 9,450,000 lb raised 1 ft high with the consumption of 1 bushel of coal (Dickinson 1938, pp. 61–62).

In 1784, Joshua Wrigley, also an engineer, installed two improved Savery steam engines at Joseph Thackery' s cotton mill in Garratt, Chorlton-on-Medlock, and Smeaton carried

[7] A unit of capacity (volume) for dery carbgo. 1 bushel = 8 gallons (Hutton 1796, entry MEASURE).

[8] The effectiveness of the engine was measured by the number of horses that it could replace (Hills and Pacey 1972).

[9] A unit of volume for water and wine. 1 hoghead = 63 gallons (Hutton 1796, entry MEASURE).

out measurements of these engines. The results were recorded in John Farey's '*Treatise on the Steam Engine*', published in London in 1827, as follows:

> The other engine was larger. The cylindrical receiver was 2 ft. diameter within side, and 7 ft. high. It delivered the water at 19 ft. high above the surface of the water in a well, and it made 7¼ strokes per minute, each stroke filling the receiver 6 ft. high. The quantity is 18¾ cub. ft. per stroke, or 136 cub. ft. per minute, raised 19 ft.; that is very nearly five horse power.
>
> This engine consumed 32 cwt. of coals in 24 h, or 1 ¾ bushels per hour; and at that rate, each bushel would raise nearly 5 ½ million pounds weight 1 ft. high (quoted in Hills 1970, p. 139).

4 Empirical or Theoretical

Is the weight raised per minute multiplied by the height of elevation an obviously empirical measure of the effectiveness of motor engines? According to Hills and Pacey, the answer is yes.

> …one simply had to know the quantity of water involved and the height through which it had to be lifted. These two quantities multiplied together formed a fairly obvious empirical measure of the effectiveness of the pump and were used rather loosely to discuss the drainage of mines even before the steam engine was invented. By the end of the eighteenth century, this procedure had been fully rationalized by Smeaton, Watt and others…. (Hills and Pacey 1972, p. 29)

However, Donald Cardwell, based on the absence of such a measure in Renaissance texts about motor engines, has a different opinion. According to him, this idea presupposes taking Galileo's principle, that is principle of virtual velocities, into consideration.

> Mining, the greater power-using industry, required, as a natural measure, the raising of a given weight a given distance in a given time. Inevitably as this seem, it was not empirical. For one thing, it is clear that craft practice could not give rise to such a measure. More important still, the idea of taking the product of weight and distance moved in unit time necessarily implies understanding and acceptance of Galileo's principle. (Cardwell 1967, p. 215)

I will try to examine this question under the light of results offered by science education research. Roselyn Driver, summarizing literature on students' intuitive ideas concerning natural phenomena and scientific concepts, remarked that usually students confuse the concepts of 'work', 'energy' and 'power' with the concept of 'force', and that this confusion is not just at a linguistic but at a conceptual level as well (Driver et al. 1994). Similar results were put down by Kevin de Berg in a more recent survey of relevant literature (de Berg 1997).

Driver and Warrington conducted a study in an English private school with 28 academically competent male students, using individual interviews. The objective was to explore students' comprehension of energy concepts in solving written and practical problems. The researchers found that, while examining the 'work' done by a man who lifts a load, with or without a pulley system, only a minority of students did take account of both force and distance (Driver and Warrington 1985, p. 173).

Furthermore, scientist Roman Sexl noticed that in everyday life situations the concept of 'work' (as a measure of labor) was related mainly with the time spent and not with the distance covered.

The use of working hours and working days in everyday life might even suggest a definition of work as the product of force and time! The standard definition of work is justified only at a later stage when it is shown that 'work' equals the change of energy of a system (Sexl 1981, p. 287).

Later on, Lillian McDermott's research at University of Washington, on the ability of college students to apply work-energy relations to actual physical systems, confirmed these remarks. The time that a constant force was applied to a body considerably affected students' estimation of the energy the body obtained regardless of the distance covered (McDermott 1984, p. 31).

Additionally, in Driver and Warrington's study, the researchers observed that only 10% of the students tried to solve the above problems using the concepts of 'work' or 'energy' (Driver and Warrington 1985, pp. 173–175). Many students structured their responses in terms of immediate perception features (e.g., 'the slope helps it') or more direct characteristics of the situation (e.g., forces). These results were interpreted as follows:

> In this study, students appeared to be more confident thinking about a problem as a time dependent sequence of events; this is, after all, the way it presents itself in experience, and so can more easily be imagined. By contrast, an analysis of a system in energy terms does not relate to physical experience and cannot be checked in the same way…. (Driver and Warrington 1985, p. 175)

This preference in interpreting situations as a sequence of events, successive in time, (a procedure that is related to forces) appears to be an intuitive way of conceiving everyday phenomena, which is based upon experience. On the contrary, describing them in energy terms, where only the overall result at a given time counts, from the initial to the final state, ignoring intermediate stages or causal mechanisms, seems to be a distant from experience way of conceiving phenomena, which more or less requires additional conceptual resources that most students lack.

Of course, science education research depicts contemporary students' intuitive ideas, not those of people in the eighteenth century. If, however, we take into account the fact that such intuitive ideas have a remarkable geographical recurrence, with students having almost the same ideas in different countries (Driver et al. 1985, pp. 2–3), it is reasonable to suppose an analogous stability as regards time. If this is true, then Cardwell has a strong point: products of 'weight raised per unit time by height' or 'force applied per unit time by height' are not likely to be obvious empirical measures of the effectiveness of motor engines. Additionally, if today, when we speak a language laden with energy concepts, we can hardly conceive or use a physical quantity like 'work', it must have been even harder to conceive it in the eighteenth century, when energy concepts did not exist at all.

5 Was It a 'Rule of Thumb'

It is well known that engineers, based on their long experience, often formulate empirical 'rules of thumb' in order to direct engineering practice (Mitcham 1994). Why, then, should not calculation of motor engine's efficiency be regarded a result of the engineers' long experience of these engines that was adopted as a 'rule of thumb'? In this question, it is obvious, science education research can not help. History of science and technology, on the

contrary, do offer some clues. Motor engines (mainly water wheels) and pumps have been used in European mines since the Middle Ages, and no measure of their effectiveness had been recorded before eighteenth century (Cardwell 1967, p. 215). Although Georgius Agricola, for example, systematically described pumps in the mines and their mode of operation, nevertheless he did not mention any measure of their efficacy (Agricola 1556, pp. 171–200). What happened between the sixteenth and eighteenth century was the appearance of the new science and its diffusion among the European and especially the British population, something which affected the development of a quantitative approach to the engineering practice (Morton 1994; Dobbs and Jacob 1995, pp. 110–124).

Another clue comes from the first attempts to construct a theory for the moving engines. When, in the first half of the eighteenth century, engineers with some theoretical background, like John Theophilus Desaguliers, Henry Beighton and Marten Triewald, attempted to analyze steam engines, their analyses were based on static forces and the balance of forces (Desaguliers 1734, p. 482; Dickinson 1938, p. 45; Triewald 1734, p. 16). In France, Antoine Parent based his mathematical analysis of water wheels on the 'quantity of motion'; a quantity closely related to Newtonian forces[10] (Parent 1704). All these analyses were not taking into account the whole product of the engine over a certain period of time and were proven to be inadequate to cover engineers' needs. Theoretical analyses of moving engines had not taken into consideration the practical measure of motor engines' effectiveness (i.e., 'duty') until the beginning of the nineteenth century. This demonstrates how difficult proved to conceive a physical measure like 'work' and use it in order to solve practical problems. In fact 'work', as a measure of labor and a concept of mechanics, was constructed when the empirical practice of engineering and the theoretical practice[11] of rational mechanics were combined by the French engineers–savants in the first third of the nineteenth century (Grattan-Guinness 1984; Chatzis 1997; Darrigol 2001).

An additional question would be whether British engineers of the eighteenth century were aware of the new science and especially of theory of statics, and could have heard of the principle of virtual velocities. According to the traditional historiographical view, this is highly unlikely. It is taken for granted that technical change in the eighteenth century, and technical change in general, at least until the middle of the nineteenth century, had not been related directly to scientific development and had not presupposed sound scientific knowledge (Cohen 1994, pp. 192–195; Wengenroth 2003). According to another view, stated by Musson and Robinson (1969, pp. 10–59), and more recently by Margaret Jacob (Dobbs and Jacob 1995, pp. 110–124; Jacob 1997, pp. 99–115, 1998), what played an important role in Britain's technical development, in the eighteenth century, was the diffusion among British people of a popularized scientific culture, and its connection with practical applications. This diffusion, much greater than any other European country, occurred mainly through unofficial routes, e.g., by wandering lecturers and popularizers, and, according to Jacob, contributed to the formation of a 'mental capital' for Britain's industrialization (Dobbs and Jacob 1995, pp. 114–115). If we accept this view, then the acquaintance of the eighteenth century British engineers with the new science, and of course statics, was at least possible. Consequently, Cardwell's position for a theoretical origin of steam engine's measure is equally probable.

[10] According to Newton's second law (Newton 1999, p. 416) force is proportional to the change of motion (i.e., quantity of motion). However, since Parent's analysis is rather prenewtonian, this remark, although valid from a today's perspective, has an anachronistic flavor.

[11] On theoretical practice see Hacking 1983 and Rouse 1999.

6 Conclusion

The principle of virtual velocities appeared in antiquity, was used by Galileo and Descartes, and became part of modern mechanics, as a fundamental principle, in the eighteenth century. The product of the weight raised by a simple machine multiplied by the height of its elevation played a central role in this principle. British engineers of eighteenth century used the same product (although not explicitly stated as a product) in order to formulate the measure of steam engine's effectiveness. The examined question here is whether this practical measure was obviously empirical or had its origin in the theory of mechanics.

According to science education research:

- Estimating the work done by a man who lifts a body, students tend to examine only the applied force while ignoring the height of elevation.
- When a force is applied to a body, students appear to believe that the time of application determines the energy the body obtains, whatever the distance covered may be.
- Students have difficulty with interpreting energy change problems in terms of 'work' and 'energy' (which are related to total results in a given time) and opt to describe them in terms of more direct characteristics of the system, such as forces (which are related to sequences of successive events and causal mechanisms).

All these lead us to the conclusion that the product 'weight raised per time unit multiplied by height', as a measure of the effectiveness of a motor engine, can not arise intuitively or directly from experience, and presumably could not have been conceived without some knowledge of theory of mechanics. This conclusion has been supported by recent studies in the history of industrial revolution, which show the relation between industrial revolution and its antecedent scientific one, and especially the contribution of the dissemination of scientific ideas amongst the British population to the technological innovations during the eighteenth century.

References

Agricola G (1556) De re metalica (trans. Hoover HC, Hoover LH). Dover, New York, 1950

Archimedes (1972) On the equilibrium of planes or the centers of gravity of planes In: Heiberg IL (ed) *Opera omnia*, vol II. Teubner, Stuttgart

Aristotle (1980) Mechanical problems. In: Wett WS (trans) Minor works, LOEB Classical Library. Harvard University Press, Cambridge, MA

Cardwell D (1967) Some factors in the early development of the concepts of power, work and energy. Br J Hist Sci 3(11):209-224

Chatzis K (1997) Économie, Machines et Mécanique Rationnelle: la Naissance du Concept de Travail chez les Ingénieurs-savants Français, entre 1819 et 1829. Annales des Ponts et Chaussées 82:10–20

Cohen HF (1994) The scientific revolution: a historiographical inquiry. University of Chicago Press, Chicago

Darrigol O (2001) God, waterwheels, and molecules: Saint-Venant's anticipation of energy conservation. Hist Stud Phys Biol Sci 31(2):285–353

de Berg K (1997) The development of the concept of work: a case where history can inform pedagogy. Sci & Educ 6:511–527

Desaguliers JT (1734 & 1744) A course of experimental philosophy, vol I & II. Innys, Senex & Longman, London

Descartes R (1996) Oeuvres. In: Adam C, Tannery P (eds), Vrin, Paris

Dickinson HW (1938) A short history of the steam engine. Frank Cass & Co. Ltd., London, 1963

Dobbs BJ, Jacob M (1995) Newton and the culture of Newtonianism. Humanities Press, New Jersey

Driver R, Warrington L (1985) Students' use of the principle of energy conservation in problem situations. Phys Educ 20:171–176

Driver R et al (1985) Children's ideas and the learning of science. In: Driver R et al (eds) Children's ideas in science. Open University Press, Milton Keynes
Driver R et al (1994) Making sense of secondary science: research into children's ideas. Routledge, London
Duhem P (1905 & 1906) The origins of statics, vol. I & II. Kluwer, Dordrecht, 1991
Galileo Galilei (1632) Dialogue concerning the two chief world systems: ptolemaic and copernican (trans: Drake S). Modern Library, New York, 2001
Galileo Galilei (1960) On mechanics, transl. by S. Drake from a collation made by A. Favaro from manuscripts and earlier printed editions. In: Drabkin IE, Drake S (eds) On motion and on mechanics. University of Wisconsin Press, Madison
Grattan-Guinness I (1984) Work for the workers: advances in engineering mechanics and instruction in France, 1800–1830. Ann Sci 41:1–33
Hacking I (1983) Representing and intervening: introductory topics in the philosophy of natural sciences. Cambridge University Press, Cambridge
Hiebert E (1962) Historical roots of the principle of conservation of energy. Arno Press, New York 1981
Hills R (1970) Power in the industrial revolution. Augustus M. Kelley, New York
Hills R, Pacey AJ (1972) The measurement of power in early steam-driven textile mills. Technol Cult 13:25–43
Hutton C (1796) Mathematical and philosophical dictionary, 2 vols. Johnson & Robinson, London
Jacob M (1997) Scientific culture and the making of the industrial west. Oxford University Press, Oxford
Jacob M (1998) The cultural foundations of early industrialization: a project. In: Berg M, Bruland K (eds) Technological revolutions in Europe: historical perspectives. Edward Elgar, Cheltenham, UK
Koliopoulos D, Dossis S, Stamoulis E (2007) The use of history of science texts in teaching science: two cases of an innovative, constructivist approach. Sci Educ Rev 6(2):44–56
Maggie FW (ed) (1969) A source book in physics. Harvard University Press, Cambridge, MA
Matthews MR (1994) Science teaching: the role of history and philosophy of science. Routledge, New York
McDermott L (1984) Research on conceptual understanding in mechanics. Phys Today 1984:24–32
Mitcham C (1994) Thinking through technology: the path between engineering and philosophy. University of Chicago Press, Chicago
Morton AQ (1994) Men and machines in mid-18th century London. Trans Newcomen Soc 1993–1994, 64:47–56
Musson AE, Robinson E (1969) Science and technology in the industrial revolution. Gordon and Breach, New York 1989
Newton I (1999) The principia (trans: Cohen IB, Whitman A). University of California Press, Berkeley
Parent A (1704) Sur la plus grande perfection possible des machines. Histoire de l' Académie Royale des Sciences, Année 1704(MDCCXLV):323–338
Roche J (1998) The mathematics of measurement: a critical history. Athlone Press, London
Rouse J (1999) Understanding scientific practices: cultural studies of science as a philosophical program. In: Biagioli M (ed) The science studies reader. Routledge, London
Seroglou F, Koumaras P (2001) The contribution of the history of physics in physics education: a review. Sci & Educ 10(1–2):153–172
Sexl RU (1981) Some observations concerning the teaching of the energy concept. Eur J Sci Educ 3:285–289
Triewald M (1734) A short discription of the fire- and air-machine at the Dannemora Mines, Stockholm, transl. by Newcomen Society in 1928, electronic reproduction in December 1996. Available at http://www.history.rochester.edu/steam/trievald
Wengenroth U (2003) Science, technology, and industry. In: Cahan D (ed) From natural philosophy to the sciences: writing the history of nineteenth-century science. University of Chicago Press, Chicago

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